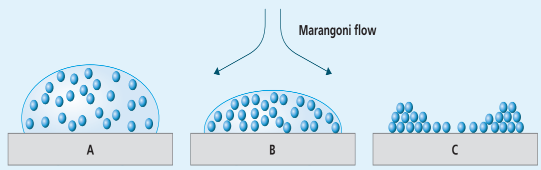
5 Most Common Nanoparticle Deposition Methods

With increasing interest to deposit nanoparticles on solid substrates, lots of studies has been done to do that most efficiently. Below the most commonly used nanoparticle deposition methods are reviewed.

Self-assembly During Solvent Evaporation

Seemingly most simple method for nanoparticle deposition is the self-assembly during solvent evaporation. Here a colloidal suspension of nanoparticles is pipetted on the solid substrate and the solvent is let to evaporate.

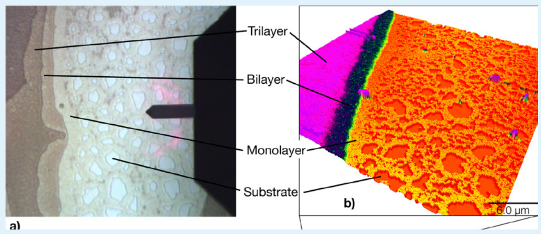
The main challenge to this method is the "coffee-ring effect" where Marangoni flow causes the sedimentation of the nanoparticle at the outer ring of the droplet. This leads to non-uniform deposition of the nanoparticles where bi-, tri- or multilayers structures are formed at the edges.



(Figure 1) *Schematics of the Marangoni flow. (a) Colloidal solution pipetted on the solid substrate. (b) Evaporation of the solvent causes Marangoni flow towards the edges of the droplet (c) Marangoni flow causes the accumulation of the nanoparticles on the outer ring of the droplet.*

Pros/Cons

- \+ Simple
- \+ Small amounts of colloidal solution required
- \- Difficult to control
- \- Produces multilayer structures

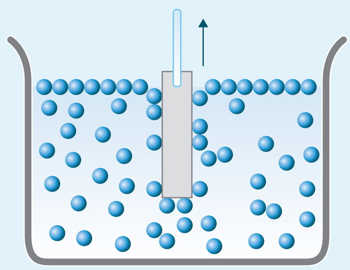


(Figure 2) *Evaporation assembly of polystyrene colloidal solution. (a) Optical and (b) AFM images of nanoparticle layers Adapted with permission from [1]. Copyright Dr. Alaric Taylor.*

Dip Coating

This technique is simple, yet versatile method for creating various coatings in fields such as biomaterials, electronics or sensors.
Dip coating refers to a method where substrate is dipped vertically into colloidal solution, pulled out and solvent is let to evaporate. Many factors effect on the quality of the thin film, like functionality of the initial substrate surface, submersion time, withdrawal speed, solution composition, concentration and temperature.

To precisely control the dipping parameter, computer controlled dip coaters are typically utilized. After the first dip coating cycle, the nanoparticle layer typically has defects and thus multiple dipping cycles are used. This may lead non-uniform coating and dip coaters are thus often used in applications where precise layer composition is not critical, like superhydrophilic and -phobic coatings [2].



(Figure 3) *Schematic of nanoparticle dip coating process.*

Pros/Cons

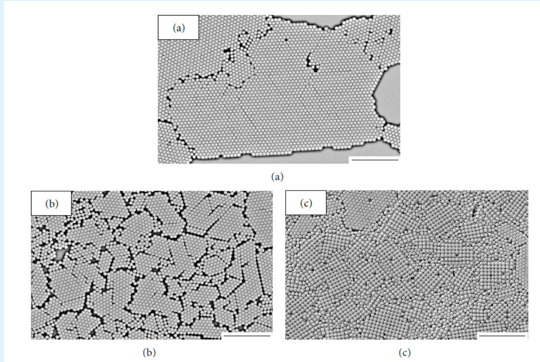
- \+ Simple
- \+ Substrates with irregular shape can be coated
- \- Large amount of colloidal solution required
- \- Monolayer coatings require controlled surface chemistry of substrate and nanoparticles

Spin Coating

Spin coating offers an attractive deposition method also for nanoparticles as it has been commonly used in lithography processes and could be scaled-up. The quality of the film depends on variate of parameters like, spin acceleration and speed, size of the nanoparticles, the wettability of the substrate and the solvent used etc. Finding the suitable processparameters can be tedious and requires relatively large amounts of colloidal solutions.

Pros/Cons

+ Well-established technique for polymer film formation in microchip processing
- Multiple process parameters that needs to be optimized separately for each nanoparticle and substrate
- Large, defect-free monolayer areas difficult to achieve
- Large amount of colloidal solution required



(Figure 4) *Polystyrene nanoparticles deposited by spin coating (with different parameters) (a) large hexagonal closed packed area (b) small hexagonal closed packed areas (c) multilayer structures Scale bars 5µm. "Reprinted from [3]. Copyright (2011) American Chemical Society".*

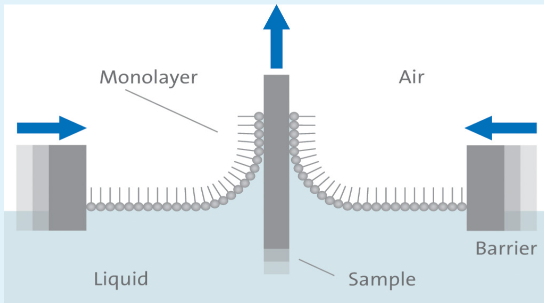
Langmuir-Blodgett Coating

In Langmuir-Blodgett technique nanoparticles are spread on the air-liquid interface, compressed in closed-packed monolayer and transferred to substrate by pulling it through the interface.
The method is well established for deposition of amphiphilic molecules but its power in the deposition of nanoparticles has been discovered only recently.

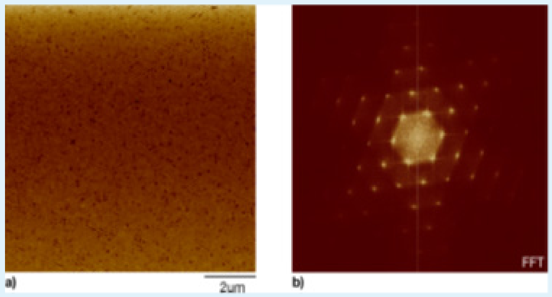
The deposition parameters include subphase composition, solvent where nanoparticles are dispersed and compression and withdrawal speed. The main advantage of the technique is the possibility to control the packing density of the nanoparticles as well as layer thickness as multiple dipping cycles are possible.

Pros/Cons

+ Controlled packing density
+ Monolayer or controlled multilayer structures easily achieved
+ Homogenous deposition over large areas
+ Only small amount of colloidal solution required



(Figure 5) *Schematics of Langmuir-Blodgett technique*



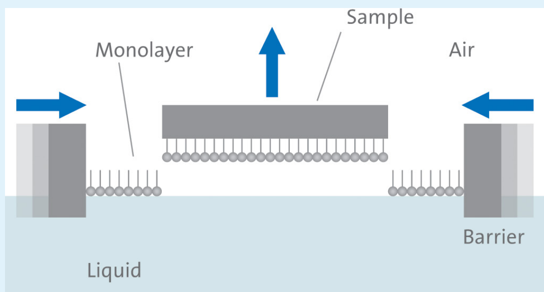
(Figure 6) *A monolayer of 200nm-diameter polystyrene nanospheres deposited on a quartz substrate using the Langmuir-Blodgett technique on a KSV NIMA Medium trough. (a) AFM image of the monolayer, (b) a Fourier transform of the same image exhibiting the exceptional crystallinity achievable with this technique. Copyright Dr. Alaric Taylor.*

Langmuir-Schaefer Coating

In Langmuir-Schaefer technique, the principle of the method is very similar to Langmuir-Blodgett. Here, however after compression of monolayer, the deposition is done vertically.The main benefit in addition to ones discussed previously, is that the deposition is done only on one side of the substrate.

Pros/Cons

+ Controlled packing density
+ Monolayer or controlled multilayer structures easily achieved
+ Homogenous deposition over large areas
+ Only small amount of colloidal solution required
+ Deposition to only one side of the substrate



(Figure 7) *Schematics of Langmuir-Schaefer technique*

References: [1] Taylor, A. "Motheye smart windows Bio-inspired, temperature-responsive glazing for passive regulation of building temperature with the ability to self-clean" (Unpublished doctoral thesis). (2016) University College London, London, UK.[2] R.A. Fleming and M. Zou, "Silica nanoparticle-based films on titanium substrates with long-term superhydrophilic and superhydrophobic stability", Applied Surface Science 280 (2013) 820. [3] P. Colson, R. Cloots and C. Henrist, "Experimental design applied to spin coating of 2D colloidal crystal masks: A relevant Method?", Langmuir 27 (2011) 12800.